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UTILITY PATENT APPLICATION

FOR

Tunable Optical Add/Drop Device

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CROSS-REFERENCE TO RELATED APPLICATION

[0001] This application is a continuation-in-part of U. S. Application No. 10/144,596, filed 5/10/2002, and entitled "Tunable Wavelength Filter with Invariant Transmission and Reflection Beam Angles," which is hereby incorporated by reference.

BACKGROUND OF THE INVENTION

Field of the Invention

[0002] The invention is generally related to the area of optical communications. In particular, the invention is related to a method and apparatus for processing optical channel or channel band signals with specified wavelengths, and more particularly, to optical add/drop devices and the method for making the same.

The Background of Related Art

[0003] The future communication networks demand ever increasing bandwidths and flexibility to different communication protocols. DWDM (Dense Wavelength Division Multiplexing) is one of the key technologies for such optical fiber communication networks. DWDM employs multiple wavelengths or channels in a single fiber to transmit in parallel different

communication protocols and bit rates. Transmitting several channels in a single optical fiber at different wavelengths can multi-fold expand the transmission capacity of the existing optical transmission systems, and facilitating many functions in optical networking.

[0004] There are many optical parts/devices used in the optical fiber communication networks. Optical tunable filter is one of the optical parts/devices widely used in many important fiber optical applications, such as, optical add/drop modules, optical cross connect systems and tunable receivers. An ideal filter is a device which can isolate an arbitrary spectral band with an arbitrary center wavelength over a broad spectral range. Accordingly, a tunable filter is known or desired to be able to transmit at any given wavelengths with some minor turning adjustments.

[0005] There are many ways of making a filter with tuning capability and, consequently, many types of tunable filters. These include those using fiber Bragg grating and tunable acoustical filter (TAOF), traditional interferometers such as Fabry-Perot, and liquid crystal filters. All have advantages and limitations and are ended up with a trade-off among the technical feasibility, the performance demands and costs. On the other hand, it is often needed to select a signal with a particular wavelength from a multiplexed signal with a group of wavelengths. This is advantageous in order to drop/add the same or different channel signals at various points within an optical network. Optical add/drop devices are often employed to add/drop one or more of these channel signals. It is desirable to have tunable filters that have the advantages of simple structure, good performance, high reliability and low cost.

SUMMARY OF THE INVENTION

[0006] This section is for the purpose of summarizing some aspects of the present invention and to briefly introduce some preferred embodiments. Simplifications or omissions may be made to avoid obscuring the purpose of the section. Such simplifications or omissions are not intended to limit the scope of the present invention.

[0007] The present invention is related to designs of optical devices for processing optical channel or channel band signals with arbitrarily specified wavelengths over a predefined spectral range. According to one aspect of the present invention, an optical filter, such as a thin film filter with a bandpass WDM filter coating on one side and an antireflection (AR) coating on the other side, is integrated with a high-reflective (HR) mirror. Specifically, the optical filter and the mirror are integrated such that the mirror rotates accordingly when the optical filter rotates. The integrated part, also referred to as a filter mirror assembly, is then rotatably mounted around a rotation axis positioned at an intersection of the incident side of the optical filter and the reflecting side of the mirror.

[0008] In general, the optical filter has a frequency response of a bandpass filter and the center bandpass frequency depends on an incident angle at which an incoming optical signal impinges upon the filter coating side of the optical filter. As a result, the beam angles of the transmitted signal as well as the reflected optical signal are invariant to the rotation of the filter mirror assembly around the axis, and thus invariant to the incident angle of the incoming signal to the optical filter. By positioning the rotation axis at the intersection, not only the beam angle but the total

position of the reflected beam will be invariant to the rotation of the filter-mirror assembly. Therefore, a wide range of wavelengths can be selected to transmit through the optical filter, and kept the reflected signal uninterrupted.

[0009] The present invention may be implemented as an apparatus and a method. According to one implementation, the present invention is an optical device comprising an optical filter having an incident side, a frequency response of the optical filter to an incoming signal depending on an incident angle of the incoming signal to the incident side; a mirror having a reflecting side and integrated with the optical filter to form an integrated part rotatably mounted on a rotation axis such that the mirror rotates accordingly when the optical filter is caused to rotate to a position in response to a selected wavelength; and a compensator configured to rotate oppositely with the optical filter to compensate a lateral shift in a light beam passing through the optical filter.

[0010] According to another implementation, the present invention is an optical device comprising a filter mirror assembly including an optical filter having an incident side, a frequency response of the optical filter to an incoming signal depending on an incident angle of the incoming signal to the incident side and a mirror having a reflecting side, the filter mirror assembly rotatably mounted on a rotation axis such that the mirror rotates accordingly when the optical filter is caused to rotate to a position to select a wavelength; a first collimator optically coupled to the optical filter; a second collimator optically coupled to the mirror; a third collimator; and an optical compensator optically coupled between the filter mirror assembly and the third collimator, wherein the compensator performs in accordance

with the optical filter to cancel or minimize a lateral shift when a light beam goes through either one of the optical compensator and the optical filter.

[0011] There are numerous benefits, features, and advantages in the present invention. One of them is a simple structure, good performance, high reliability and low cost in the tunable filters contemplated in the present invention

[0012] Other objects, features, and advantages of the present invention will become apparent upon examining the following detailed description of an embodiment thereof, taken in conjunction with the attached drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0013] These and other features, aspects, and advantages of the present invention will become better understood with regard to the following description, appended claims, and accompanying drawings where:

[0014] FIG. 1A shows an optical device including an optical filter integrated with a mirror to facilitate the understanding of the present invention;

[0015] FIG. 1B shows characteristics of an exemplary optical filter;

[0016] FIG. 2 shows that a filter mirror assembly including an optical filter and a mirror has been rotated around a rotation axis from a position P1 to a new position P2;

[0017] FIG. 3A shows an optical filter according to one embodiment of the present invention;

[0018] FIG. 3B shows exemplary real tray tracing at three beam incident angles in which the reflected beam and the incident beam are kept the same position when the filter mirror assembly is rotated from 20 to 30 and to 40 degree;

[0019] FIG. 3C shows a measurement of a lateral shift versus an incident angle onto the filter mirror assembly;

[0020] FIG. 4 shows an exemplary mechanical structure that may be used to control the rotation of the filter mirror assemble as well as the compensator as shown in FIG. 3A;

[0021] FIG. 5A shows a different configuration of the filter mirror assembly in which the angle between the thin film filter and the mirror is less than a right angle, for example 85 degree; and

[0022] FIG. 5B shows an exemplary situation in which an optical compensator is not positioned perfectly systemic to a filter mirror assembly about a vertical bisector line, resulting in a two-degree offset in angle causes 0.1dB insertion loss increase at 20° incident angle.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0023] In the following description, numerous specific details are set forth in order to provide a thorough understanding of the present invention. However, it will become obvious to those skilled in the art that the present

invention may be practiced without these specific details. The description and representation herein are the common means used by those experienced or skilled in the art to most effectively convey the substance of their work to others skilled in the art. In other instances, well-known methods, procedures, components, and circuitry have not been described in detail to avoid unnecessarily obscuring aspects of the present invention.

[0024] Reference herein to "one embodiment" or "an embodiment" means that a particular feature, structure, or characteristic described in connection with the embodiment can be included in at least one embodiment of the invention. The appearances of the phrase "in one embodiment" in various places in the specification are not necessarily all referring to the same embodiment, nor are separate or alternative embodiments mutually exclusive of other embodiments. Further, the order of blocks in process flowcharts or diagrams representing one or more embodiments of the invention do not inherently indicate any particular order nor imply any limitations in the invention.

[0025] Embodiments of the present invention are discussed herein with reference to FIGS. 1A– 5B. However, those skilled in the art will readily appreciate that the detailed description given herein with respect to these figures is for explanatory purposes as the invention extends beyond these limited embodiments.

[0026] FIG. 1A shows an optical device **100** that may be used to facilitate the understanding of the present invention. The optical device **100** is capable of maintaining beam direction and angle of both transmission beam and reflection beam while rotating a filter mirror

assembly relatively to an incoming optical beam or signal (e.g., a multiplexed signal) with a plurality of wavelengths. The filter mirror assembly includes an optical filter **102** and a mirror **104**.

[0027] As shown in the figure, the filter mirror assembly appears an "L" shape and provides a filtering function as well as a reflecting function. As will be detailed more below, the angle between the optical filter **102** and the mirror **104** does not have to be a right angle (i.e., 90 degree). The drawing showing a 90 degree is for easy understanding only and shall not be understood as an implied limitation of the current invention.

[0028] According to one embodiment, the optical filter **102** is so chosen that the frequency response thereof to an incoming signal depends on an incident angle of the incoming signal coming to its incident side **106** while the mirror is preferably of high reflection. FIG. 1B shows characteristics of an exemplary optical filter. A pass-through wavelength of the optical filter changes when the incident angle changes. For example, at an incident angle of 0 degree, the pass-through wavelength is 1550 nm while, at an incident angle of 27 degree, the pass-through wavelength is 1470 nm.

[0029] In general, the optical filter **102** has two sides, preferably, a bandpass WDM filter coating on one side and an antireflection (AR) coating on the other side with both side substantially parallel with each other. Depending on the use of the optical device **100**, either side can be an incident side to receive an optical signal. To facilitate the description of the present invention, it is assumed that the optical device **100** is used to

drop or filter out a specific (selected) wavelength from an incoming multiplexed signal **107** as shown in FIG. 1A.

[0030] In operation, the incoming signal or light beam **107**, assumed to have wavelengths λ_1, (2, …, and (N, is coupled from a collimator 110 to the optical filter 102. According to a particular requirement, for example, only a signal with wavelength (j ($1 \leq j \leq N$) is to be transmitted through the optical filter 102 positioned at a particular position (angle), for example, P1, at the same time, the remaining wavelengths in the signal 107 (i.e., the reflected signal 114) are reflected to the mirror 104 that further reflects the reflected signal 114 to a collimator 116.

[0031] As a result, the collimator 110 couples in the incoming signal 107 with wavelengths (1, (2, …, and (N, the collimator 112 outputs a transmitted signal 111 at a selected wavelength (j and the collimator 116 outputs the reflected signal 114 with all wavelengths except for the selected wavelength (j.

[0032] When there is a need to alter the selection of the transmitted wavelength (j to (i, wherein $1 \leq i, j \leq N$ and $i \neq j$, the filter mirror assembly can be rotated accordingly to a new position, for example, P2. Referring now to FIG. 2, it shows that the integrated optical filter 102 and the mirror 104 have been rotated around a rotation axis **200** from a position P1 **202** to a new position P2, **204**. Because the incident angle of the signal **107** is changed, only a signal with wavelength λ_i is transmitted through the optical filter **102** positioned at the present position, at the same time, the remaining wavelengths in the signal **108** are reflected to the mirror **104** that further reflects the reflected signal **114** to the collimator **116**.

[0033] According to one embodiment of the present invention, FIG. 3A shows an optical device **300** that may be readily understood if viewed in conjunction with FIGS. 1A-2. It is assumed that the device **300** is used to drop a selected wavelength λ_j. Accordingly, the device **300** includes a filter mirror assembly **302** and a compensator **304** in addition to three collimators **306**, **308** and **310** that are respectively labeled as input port collimator, express port collimator and transmission port.

[0034] In one embodiment, the filter mirror assembly **302** is similar to that in FIG. 1A and appears an "L" shape and provides a filtering function as well as a reflecting function. The filtering function is provided by, for example, a thin film filter **312** on top of a substrate **314**, and the reflecting function may be simply provided by a mirror **316**. As described above, when the filter mirror assembly **302** is controlled at a certain angle, only one selected wavelength λ_j in a light beam can pass through the thin film filter **312** and the substrate **314** to the transmission port collimator. The rest of the light beam with wavelengths other than the selected wavelength λ_j is reflected towards the mirror **316**.

[0035] The mirror **316** then redirects the beam to the direction that is parallel to the optical path of the input beam (or the input beam direction) to the express (or reflection) port **308**. One of the features of the device **300** is that the optical path of the reflected beam (or the reflected beam position) is always maintained as the same beam position of the incident beam while the filter mirror assembly **302** is controllably rotated around the rotation pivot **318**. When the angle in the filter mirror assemble **302** is other than 90 degrees, as detailed below, the incidental beam position and the reflected beam position remains unaltered, although not

necessarily being parallel. In any case, it can be shown in FIG. 3A that the separation between the incident beam position and the reflected beam position is always 2D, where D is the vertical distance between the rotation axis **318** to the incident beam position. Exemplary real tray tracing at three beam incident angles are shown schematically in FIG. 3B in which the reflected beam and the incident beam are kept the same position when the filter mirror assembly is rotated from 20 to 30 and to 40 degree.

[0036] It may be observed in FIG. 1A or FIG. 3 that, as the light beam at the selected wavelength λ_j passes the filter mirror assembly **302**, there is a certain lateral shift, noted as Δx, of the transmitted light with respect to the incident beam position. Such lateral shift Δx, observable in FIG. 1A or FIG. 3A, is largely caused by the difference between the two media. The magnitude of the lateral shift Δx depends on the combination of the thickness of the thin film filter **312** and the index of the substrate **314**. A measurement of such lateral shift versus an incident angle onto the filter mirror assembly **302** is shown in FIG. 3C.

[0037] In operation, such lateral shift Δx, depending on the magnitude thereof, ultimately affects the transmission of the light beam at the selected wavelength λ_j, thus introducing a coupling loss. Measurements of the coupling loss versus the lateral shift Δx for four given collimated beam size on the transmission port coupling loss are collectively shown in Fig. 3D. Combining these two effects together, the T-channel (transmission) coupling loss as a function of the tilting angle of the filter mirror assembly, for a fixed 1.2mm thickness substrate with an

index of refraction value 1.5, at various beam waist radii are plotted in FIG. 3E.

[0038] One of the important features in the present invention is the introduction of the compensator **304** in the device **300**. The compensator **304** is made as identical as possible to the substrate **314** such that the lateral shift Δx can be cancelled or minimized when the light beam at the selected wavelength λ_j passes the compensator **304**. In operation, the shifted light beam enters the compensator **304** and is shifted in a direction opposite to that of the substrate **314**, thus resulting in a cancellation of the lateral shift Δx or at least a minimization of the lateral shift Δx. As a result, the coupling loss is significantly reduced.

[0039] It can be readily appreciated that the above description equally applied to the applications in which a signal at a specific wavelength (e.g., λ_j) is to be combined with an incoming signal by reversing the optical paths. A resultant newly combined or multiplexed signal will be output from the collimator **306**.

[0040] FIG. 4 shows an exemplary mechanical structure **400** that may be used to control the rotation of the filter mirror assemble as well as the compensator as shown in FIG. 3A. The mechanical structure **400** includes four rigid arms **402**, **404**, **406** and **408** connected at its ends to form a frame, wherein both of the arms **406** and **408** are attached a filter **410** and a compensator **412**. The arm **408** is also extended to include a mirror **414** and thus provides an exemplary filter mirror assembly. In operation, to drop or filter out a selected wavelength, the filter mirror assembly is caused to rotate to a position where the spectral response of

the filter **410** falls on the selected wavelength. As the arm **414** rotates, because of the framing of the mechanical structure **400**, the compensator **412** moves oppositely with the filter **410**.

[0041] One of the features in the present invention is that the reflected signal always maintains the same beam position regardless how the incident angle to the optical filter **410** is changed, as long as the rotation of the filter mirror assembly is around the rotation axis which is located at the intersection of the mirror and filter coating surface of the filter.

[0042] FIG. 5A shows a different configuration of the filter mirror assembly in which the angle between the thin film filter and the mirror is less than a right angle, for example 85 degree. It shows by ray tracing that as long as the filter mirror assembly rotates about the rotation pivot, the incident light path and the reflection light path will remain unaltered. It can be appreciated that the filter mirror assembly of FIG. 5A can be still supported by the mechanical structure **400** of FIG. 4.

[0043] There are some results observed. For the reflection port, for example, **308** of FIG. 3, the angle between the filter surface and the reflection mirror surface does not have to be 90° and the incident and reflection optical paths can still maintain unchanged while rotating the filter mirror assembly. This feature has been demonstrated in FIG. 5A in which the reflection port collimator is no longer parallel to the input port collimator while the light coupling is kept at optimal condition.

[0044] For the transmission port, for example, **310** of FIG. 3A, if the compensator **304** is not positioned perfectly systemic to the filter mirror

assembly about a vertical bisector line **320**, the situation is modeled and shown in FIG. 5B, a two-degree offset in angle causes 0.1dB insertion loss increase at 20° incident angle. In operation and mechanically, such angle offset can easily be controlled under 2 degree.

[0045] The present invention has been described in sufficient details with a certain degree of particularity. It is understood to those skilled in the art that the present disclosure of embodiments has been made by way of examples only and that numerous changes in the arrangement and combination of parts may be resorted without departing from the spirit and scope of the invention as claimed. Accordingly, the scope of the present invention is defined by the appended claims rather than the foregoing description of embodiments.